ONR Grant N00014-93-1-0202 Final Technical Report: Geomorphology of Headless Submarine Canyons: Prediction of Slope Failure, Sediment Strength and Pore Pressure Gradient, and the Regular Spacing of Submarine Canyons

Daniel L. Orange
Monterey Bay Aquarium Research Institute, P.O. Box 628, Moss Landing, CA 95039
email: dano@mbari.org
direct/office phone: (408) 775-1761; messages: 775-1773; FAX: 775-1645

Project Summary

The Atlantis II/ALVIN program conducted in September, 1993 was successful in identifying cold seeps, determining their distribution, and measuring pore pressure gradients within and between the cold seeps. We identified four cold seeps; all cold seep sites were within canyons, and none were found along strike between canyons. Even though all fluid seeps were found in canyons, not all canyons had seeps, and the location of the seeps within the canyons differed on the landward and seaward limbs of the anticlines. This suggests both spatial and temporal variations on fluid flow. Our analysis of the geotechnical data we collected suggests that the ambient pore pressure gradients at the seeps in the canyons are above hydrostatic, but below that required to initiate slope failure. If these measurements represent steady-state, than some transient pressure pulse may be required to initiate slope failure. Our modeling suggests that seismicity or methane expulsion can produce the required transient.

Long Term Goal

The long term goal of this project is to understand the interaction between tectonic and hydrologic forcing and the resultant creation and modification of seafloor geomorphology.

Scientific or Technological Objectives

The initial objective of this project was to ground-truth the hypothesis that there is a causative relationship between geomorphology and fluid expulsion at the seafloor. Once that relationship was established, we sought to determine the hydrologic and geotechnical state of the venting and non-venting regions. The hydrologic and geotechnical data can be used together with the seafloor observations to model slope failure.

Background

The processes of accretion and tectonic compaction in active margins, and sediment loading and aquifer forcing in passive margins, lead to the expulsion of pore fluids and the generation of above-hydrostatic pore pressure gradients. These gradients affect the force balance of sediments at the seafloor via seepage force, and, if high enough, can destabilize a slope. When the material on a slope fails, the head gradient at the base of the failure will increase due to the decreased path length, and therefore the probability of failure increases within the pre-existing scar. This positive feedback will lead to the headward erosion of a canyon, resulting in the characteristic "headless" morphology of these features. Because the canyon imposes an indentation on the previously uniform constant head boundary at the seafloor, continued fluid expulsion will be attracted to canyons (and directed away from intervening regions). It is this hypothesis that we explored during the 1993 ALVIN program.

Approach

In order to study the interaction of tectonics and hydrology we used a combination of field work, modeling, and geotechnical and hydrological analysis. First, we used a USGS deep tow video and camera sled and the ALVIN submersible in the fall of 1993 to make direct observations of fluid venting in and around canyons on the Oregon margin. These fluid vents (cold seep communities) are comprised of unique faunal assemblages that can be used to infer the distribution of fluid expulsion on the margin. Once we determined the location of the cold seeps, we then used

M B A R I

MONTEREY BAY AQUARIUM RESEARCH INSTITUTE

P.O. Box 628
7700 Sandholdt Rd.
Moss Landing, CA
95039

SCIENCE, ENGINEERING AND ADMINISTRATION
TEL (408) 775-1700
FAX (408) 775-1620

MARINE OPERATIONS FACILITY
TEL (408) 775-1900
FAX (408) 775-1652

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Defense Technical Information Center
Building 5, Cameron Station
Alexandria, VA 22304-6145

SUBJECT: FINAL TECHNICAL REPORT
ONR AWARD NO. N00014-93-1-0202
Geomorphology of Headless Submarine Canyons: Prediction of Slope Failure, Sediment Strength and Pore Pressure Gradient, and the Regular Spacing of Canyons

Dear Director:

Per ONR Research Grant Number N00014-93-1-0202 Grant Schedule Item 8 (Reports and Report Distribution) and Attachment Number 2 (Reports and Report Distribution), I am providing you two copies of the Final Technical Report for the period ending 31 October 1995. The research project entitled ***Geomorphology of Headless Submarine Canyons: Prediction of Slope Failure, Sediment Strength and Pore Pressure Gradient, and the Regular Spacing of Canyons*** is under the direction of Dr. Daniel Orange, Principal Investigator.

If you have any questions or need additional information you may contact the undersigned by (Tel.) 408-775-1776, (FAX) 408-755-1620, or (Email) chlo@mbari.org.

Sincerely,

Lonnie G. Christiansen
Grants & Accounting Specialist

Enclosure

ALVIN to deploy the deep ocean piezometers (Portable In-Situ Pore Pressure Instruments, or PISSPIs) for measuring pore pressure gradients both within vent sites and between vent sites. The PISPPI development and construction was supported by this project and carried out by Bobb Carson, Lehigh University. These instruments can be deployed in up to 4000m of water, are capable of measuring very small pore pressure gradients in the top 1m of the seafloor, and were deployed in deep water for the first time as part of our 1993 ALVIN field program. In addition to the hydrologic data, we also collected sediment push-cores at all of the PISSPI sites (both venting and non-venting) for later geotechnical analysis. We used our observations and analyses to model the creation of headless submarine canyons. In addition, the PISPPIs were deployed at seep sites in Monterey Bay and at the toe of the Costa Rica trench to augment our seafloor geotechnical database from Oregon.

Accomplishments and Results

The Atlantis II/ALVIN program conducted in September, 1993 was successful in identifying cold seeps, demonstrating that all seeps occurred within canyons, and measuring pore pressure gradients within and between the cold seeps. On the landward limb of the second landward vergent anticline a robust cold seep community occurs at the base of the steep canyon headwall. The seep is characterized by chemoautotrophic vent clams (Calyptogena and Solemya), Vestimentiferan tube worms, and extensive authigenic carbonate. Fluids for this seep may utilize flow paths either parallel to bedding in the hanging wall of the second thrust ridge, or may travel along the underlying thrust fault itself. Two seaward facing canyons on the third landward vergent ridge have vent clam communities (Calyptogena, scattered Solemya) at a different location, namely the base of the canyon near the canyon mouth (the intersection between the anticlinal ridge and the adjacent forearc basin). No seeps were found along strike at the intersection of the slope basin and anticlinal ridge. Fluids for these seeps may originate in the section beneath the second landward vergent thrust, utilize stratigraphic conduits, and may be prevented from venting in the forearc basin by a basal unconformity.

The presence of authigenic carbonate on the second ridge canyon seep, but not the third ridge, may be attributed to a difference in fluid source. Carbonate precipitates from the oxidation of methane, whereas clam and tube worm colonies require hydrogen sulfide for survival; Vestimentiferan tube worms are thought to require higher concentrations of sulfide than clams. The difference in seep fauna and carbonate suggests that the fluids supporting the robust seep at the inflection point of the headless canyon on the second landward vergent ridge may originate at deeper levels than the seep on the third landward vergent ridge.

Impact on Science, and Transitions Accomplished or Expected, If Any:

Orange has been approached separately by two oil companies (Chevron and PetroBras) to discuss the role of seepage force in triggering sediment slope failure. Both companies are exploring platform drilling in deep water on continental slopes, and are concerned over safety issues. Based upon our work in central Cascadia we have initiated a successful collaboration with Amoco for providing industry quality multi-channel seismic data and processing relevant to the ongoing STRATAFORM project in southern Cascadia.

Relationship to Other Projects, if known:

The observations and data from this project provide limits and inputs to the slope evolution models of Pratson, Coakley, Steckler and Syvitski. In addition, the hypothesis of seepage-induced spring sapping provides constraints for the slope failure/sedimentation models of Parker, Garcia, and Syvitski. The hypothesis of geomorphology-fluid linkage provided a basis for studying the STRATAFORM research area, and provides a robust data for analyzing the gully and pock mark distribution in southern Cascadia. The initial side scan and high resolution seismic data collected in 1995, and the industry MCS data mentioned above, show that gas is abundant in the subsurface, and many slope failure features identified on the surface provide evidence of fluid involvement. Finally, the techniques that we formulated for in situ hydrological and post-cruise laboratory geotechnical analysis are applicable to the STRATAFORM analysis program planned for 1996.

Statistical Information:

Daniel Lewis Orange
Monterey Bay Aquarium Research Institute
P.O. Box 628
Moss Landing, CA 95039
email: dano@mbari.org

Publications:

Orange, D.L. and Underwood, M. B. (1995) Patterns of thermal maturity as diagnostic criteria for interpretation of mélange, Geology, v. 23, p. 1144-1148.

Orange, D.L., Anderson, R. S., and Breen, N. A. (1994), Regular canyon spacing in the submarine environment: the link between hydrology and geomorphology, G.S.A. Today, v. 4, p. 29-39.

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In Press:

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Orange, D.L., Greene, H.G., Maher, N., and Connor, J., (1995) Ground-truthing mullti-beam bathymetry and side-scan sonar with ROV studies, and creating geologic maps in Monterey Bay, California, in Geologic Mapping in the 21st Century, TERRA (Abstracts, European Union of Geosciences), v. 7, p. 28.

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Orange, D.L, Greene, H.G., Barry, J., and Kochevar, R., (1994) ROV investigations of cold seeps along faults zones and mud volcanoes in Monterey Bay, EOS (Transactions, American Geophysical Union), v. 75, p. 32.

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Graduate students:
2 Graduate Students (at University of California, Santa Cruz):
Brian G. McAdoo
Janet Yun

Number of female graduate students: 1
Number of minority graduate students: 2

Service on committees/panels:
DESSC (Deep Submergence Science Committee - formerly ALVIN review committee); 1993-1995
ONR STRATAFORM committee; Slope Working Group; 11/93 - present
Board of Directors, The Lyceum (a non-profit organization providing extracurricular education activities to primary and secondary school children in the Monterey-Salinas-Watsonville area); 9/94 - present
OBLISP (Ocean Borehole Laboratories, Instrumentation, and Sampling Program; December, 1994 - present)

Professional Societies:
American Geophysical Union
Geological Society of America
American Association of Petroleum Geologists
Society for Sedimentary Geology (SEPM)